

Ultrasensitive Bolometers for Far-IR Spectroscopy at the Background Limit

Completed Technology Project (2017 - 2020)



Project Introduction

We propose to demonstrate flight readiness with the world's most sensitive bolometers: transition-edge-sensed (TES) devices which meet the requirement for zodiacal-light-limited far-IR spectroscopy on cold space telescopes. Building on our success with single pixels and small arrays, we will fabricate and characterize TES bolometer arrays which: 1) demonstrate a per-pixel noise equivalent power (NEP) less than $1 \times 10^{-19} \text{ W}/\sqrt{\text{Hz}}$, 2) provide sufficient speed of response ($f_{3\text{dB}} > 10 \text{ Hz}$ (requirement), 15 Hz (goal)) to be useful in a range of instrument configurations, 3) are readout with a frequency-domain multiplexing scheme developed by our SRON collaborators which is scalable to enable a mission with tens of thousands of detectors at 50 mK, and 4) can maintain high duty cycle in the face of cosmic-ray interactions in space. This work on low-NEP detector development is directly applicable to future far-IR space missions such as SPICA and the Origins Space Telescope (OST). These missions feature cryogenic telescopes, which when combined with dispersive spectrographs at the background limit (hereafter referred to as BLISS-type) create powerful spectroscopic facilities with 1–4 orders of magnitude sensitivity improvement over the current state of the art. This advance will bring far-IR sensitivities into parity with those of the powerful flagship programs at shorter and longer wavelengths: JWST & ALMA, but providing unique access to the most dust-enshrouded star formation and black hole growth in the Universe's first billion years. We will build on our broad experience in all of these aspects from ground-based instrumentation, Herschel & Planck, and our work on the BLISS-specific bolometer technology to design and demonstrate a full focal-plane array system and testbed to verify performance against the requirements. While NASA's TRL level definitions are broad and subject to interpretation, we submit that the current state of the technology is TRL 4, and our proposed system-level advances will position this far-IR detector + readout technology at TRL 6, 'system demonstration in a relevant end-to-end environment.' For the TES bolometers themselves, the thermal conductance (G) and noise equivalent power (NEP) to meet the requirements have been demonstrated. The principal thrusts of this work are in eliminating excess heat capacity to speed up the devices, and showing high yield in a ~ 1000 -pixel array hybridized with backshorts and the cold multiplexer in a flight-suitable package. For the multiplexer, we are leveraging substantial investment by the Space Research Organization of the Netherlands (SRON) who have invested substantially and are continuing to develop a high-performance frequency-domain readout for TES sensors. This system will fly on Athena next decade, and, with its 176x multiplexing format, enables a far-IR instrument with many tens of thousands of pixels, comfortably meeting the SPICA targets and approaching what is needed for the envisioned OST instruments. Our program will leverage this SRON investment for potential NASA-built focal plane packages. For the cosmic-ray susceptibility, we will build on the lessons learned in the Planck High-Frequency Instrument (HFI); our team includes members of this group. The most important aspect for the is to insure that the substrates (silicon



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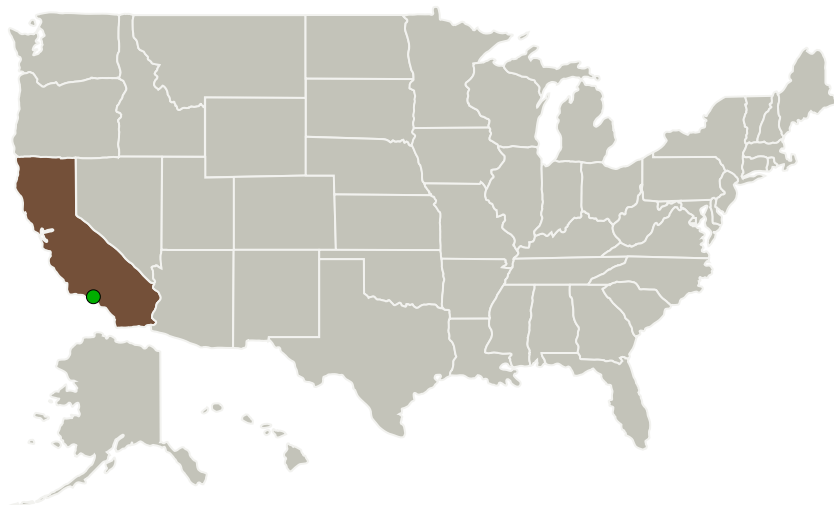
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frames) are well-thermalized internally and heat sunk. We will accomplish this on our prototype arrays with thick normal-metal films and thermal sinking wire bonds, then verify the response using a small 5-MeV alpha-particle source, which provides a comparable energy deposition to the Galactic cosmic rays. All of this work will require a new low-background testbed with a cryogenic blackbody. We will develop this beginning with a commercial 50-mK cryostat, it will be procured and modified for our purposes on an overhead-free fabrication account at Caltech.

Primary U.S. Work Locations and Key Partners



Organizations Performing Work	Role	Type	Location
California Institute of Technology (CalTech)	Lead Organization	Academia	Pasadena, California
● Jet Propulsion Laboratory (JPL)	Supporting Organization	NASA Center	Pasadena, California

Primary U.S. Work Locations

California

Organizational Responsibility

Responsible Mission Directorate:

Science Mission Directorate (SMD)

Lead Organization:

California Institute of Technology (CalTech)

Responsible Program:

Strategic Astrophysics Technology

Project Management

Program Director:

Mario R Perez

Program Manager:

Mario R Perez

Principal Investigator:

Charles M Bradford

Co-Investigators:

Karen R Piggee
Warren A Holmes
Marcus C Runyan
Steven Hailey-dunsheath
Matthew E Kenyon

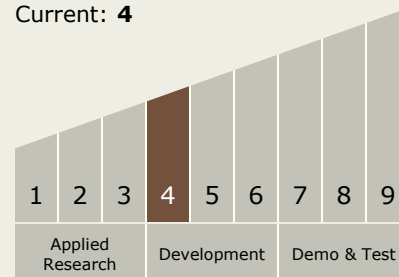
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Technology Maturity (TRL)

Start: 4
Current: 4



Technology Areas

Primary:

- TX08 Sensors and Instruments
 - └ TX08.1 Remote Sensing Instruments/Sensors
 - └ TX08.1.1 Detectors and Focal Planes

Target Destination

Outside the Solar System